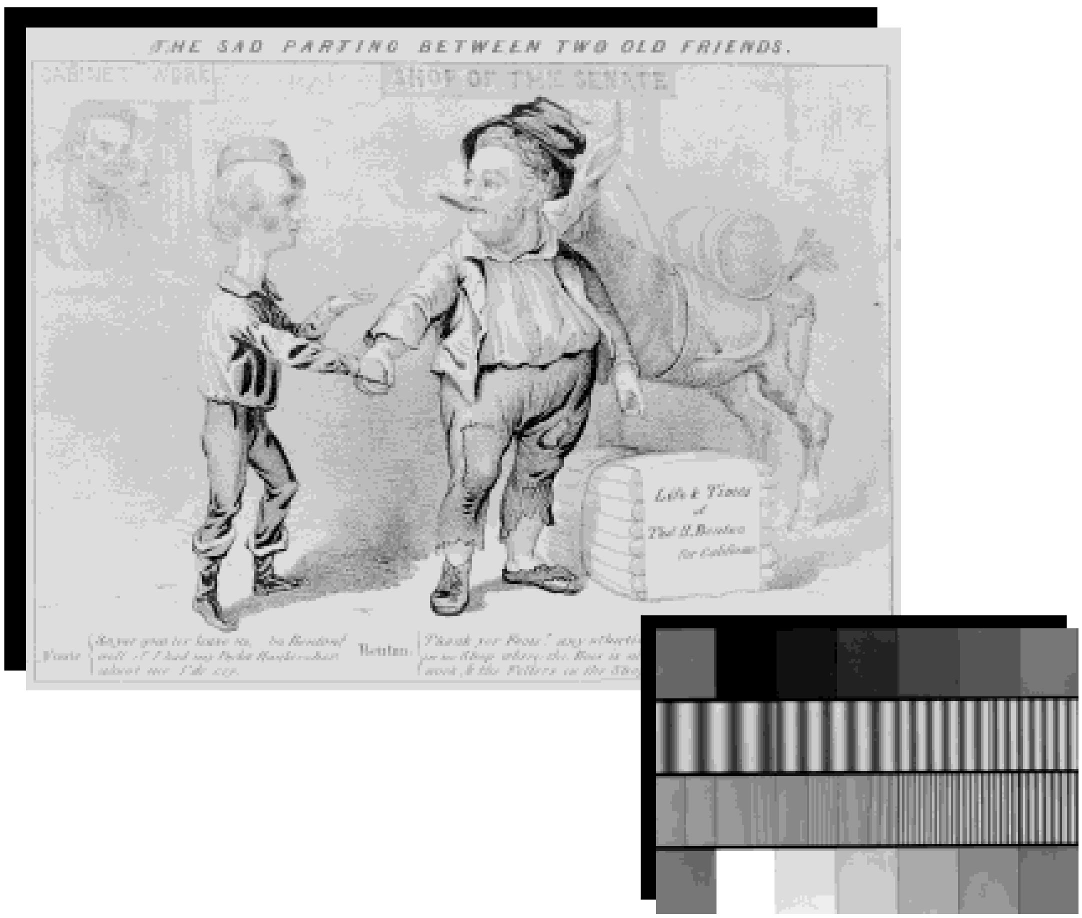
Report to the Library of Congress
National Digital Library Project
Contract # 96CLCSP7582

Recommendations for the Evaluation of Digital Images Produced from Photographic, Microphotographic, and Various Paper Formats

James M. Reilly and Franziska S. Frey



Contractor

Image Permanence Institute

Rochester Institute of Technology

Rochester, NY 14623-5604

James M. Reilly, Director

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Methodology for Evaluation of Performance and Products of Scanning Service Providers

IPI was contracted to consult on methods to evaluate the performance and products of scanning service providers hired to convert Library materials from paper, flat film, and microfilm to digital images. The Library is first of all looking for guidance for the measurement of spatial resolution. The report shall recommend quality assurance procedures to be used to create measurable images, together with a description of the tools and/or devices needed to measure the outcome of the resulting images. Specifically, the NDLP is seeking technical guidance regarding such concerns as how to perform tests after scanning to measure capture resolution (and tonality) by interpreting or reading test targets or by other means which may be suggested.

Overview

The specific questions in the contract about spatial resolution measures cannot really be addressed independently—they must be part of the larger picture encompassing other image quality parameters and work-flow issues.

The best approach to digital image quality control includes, on one hand, subjective visual inspection using monitors and printers and, on the other hand, objective measurements performed in software on the digital files themselves.

Efforts should be made to standardize the procedures and equipment for subjective evaluations by means of monitor and printer calibration. For objective image quality measurement, software should be available which is designed to locate and evaluate specific targets and then to report numbers or graphs describing key image quality parameters. Such software should ideally be a plug-in to a full-featured image browser so that review of all aspects of the image file (header info, index and tracking data, etc.) can be done at once.

A key point is that targets and the software to evaluate them are not just for vendor checking—they serve to guarantee the long-term usefulness of the digital files and to protect the investment the Library has made in creating them. Known targets that "ride" with every group of images allow for graceful migrations from one file format or computer platform to another. This additional information could be part of the image header or a separate file linked to specific batches of image files. Internal quality reference points raise the likelihood

that images can be dealt with in large batches in a controllable way, thereby leveraging the investment in all the scanning done in the first place. With digital files, targets have a continuing function that they did not have in conventional microfilming—they are like trail markers through all the manipulations and migrations.

No adequate off-the-shelf target and software solutions are commercially available. The Library will have to further examine its requirements and perhaps become involved as a partner with commercial vendors to create a product to meet its specific needs.

Suggested Approach to Vendor Qualification

To achieve the goal of building an archive of long-term value, a whole set of image quality issues should be looked at. IPI suggests including tests on tone reproduction, modulation transfer function, and noise in the quality test. For some materials, tone reproduction is not valid.

The proposed method includes two stages: first, the qualification of the vendors and, second, a quality measurement tool that can be used by customers to assure scanning quality over time. It should be kept in mind, however, that it might be difficult to carry out this second stage, because the vendor might be opposed to it. Nevertheless, the experience of similar projects has shown that once vendors accept the testing they make it part of their work flow because it helps them find and get rid of flaws in their equipment.

Tests should be conducted by scanning a given calibrated test target and evaluating the digital file with the help of a specially developed software program. The software should ideally be a plug-in to a full-featured image browser like Photoshop.

The rigorous image quality test suite for initial vendor qualification that should be included in the request for proposals involves tests for all three quality parameters (and color reproduction as well, in the case of color images); it includes test targets and sample images. Once the selection is made and the scanning has started, vendors should be checked on a regular basis. These routine quality-assessment tests can be less rigid and include only the key parameters (tone reproduction, resolution, color reproduction). Full versions of the targets could be scanned every few hundred images and then linked to specific batches of production files, or smaller versions of the targets could be included with every image. The noise of the hardware used should actually not change, unless the scanner operator changes the way he works or dirt is built up in the system.

Rigorous Vendor Qualification

One of the first steps should be to rule out so-called image defects such as dirt, "half images," skew, and so on. Whether some preliminary image manipulations (such as resampling) were done should be considered.

After this initial step, three different aspects of the scanned images should be looked at:

- Tone reproduction
- Detail and edge reproduction (MTF)
- Noise

For future projects a test for color reproduction should be included.

Each one of the above classes needs special targets for the different forms of images (e.g., prints, transparencies, etc.).

To complete the image quality framework, a number of other tests and procedures should be included in the future. Some scanner manufacturers already have software in place to test their equipment, but it is usually very specific.

For every image, corrections should be made to take care of the different "amplifying factors" of the CCDs and the nonhomogenous illumination in the scanner. Testing for flare (stray light in the optical system) might be necessary when scanning transparencies with a large dynamic range. In the case of color scans, a test for the registration (precise overlapping) of the three color channels is necessary.

Tone Reproduction

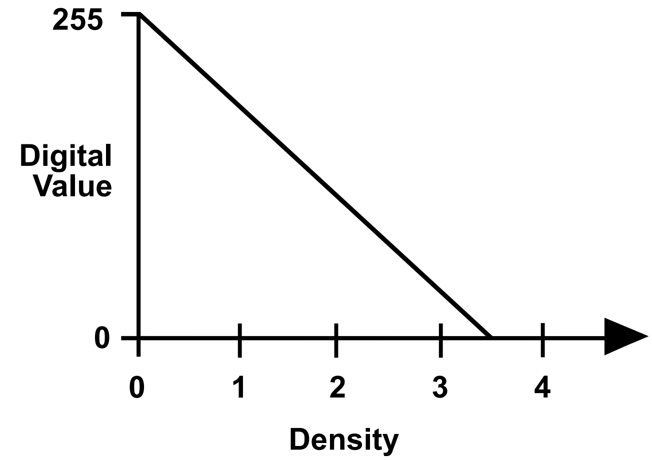
This test will show how linearly the system works regarding the density values (a logarithmic unit) of the original. Achieving linearity for scanner output means that the relationship of tonal values of the image is not distorted.

Linearity and highest achievable density depend on the optics of the systems (e.g., flare) but also on the A/D (analog to digital) converter of the system. Therefore, the highest achievable density of a system is a combination of optics and the electronics used in the A/D converter.

Fig. 1 Calibrated gray-scale test targets serve as a link back to the reality of the original document or photograph.

Reproducing the gray scale correctly usually does not result in optimal reproduction of the images. Efforts are under way in industry to automate the task of optimal image

Fig. 2 Using a calibrated gray scale and the resulting digital values, the linearity of the scanning device can be determined. The reflection or transmission density of each step of the gray scale can be measured with a densitometer. Plotting these values against the digital values of the steps in the image file show the performance of the scanning device over the whole range of densities. Specifications will have to be worked out regarding how big a deviation from the linear curve is acceptable.



reproduction with the use of a so-called Automated Pictorial Image Processing System. However, the gray scale is used as a trail marker for the protection of NDLP's investment in its digital scans; having a calibrated gray scale associated with the image makes it possible to go back to the original stage after transformations, and it also facilitates the creation of derivatives. The gray scale could be part of the image, or the file header could contain the digital values.

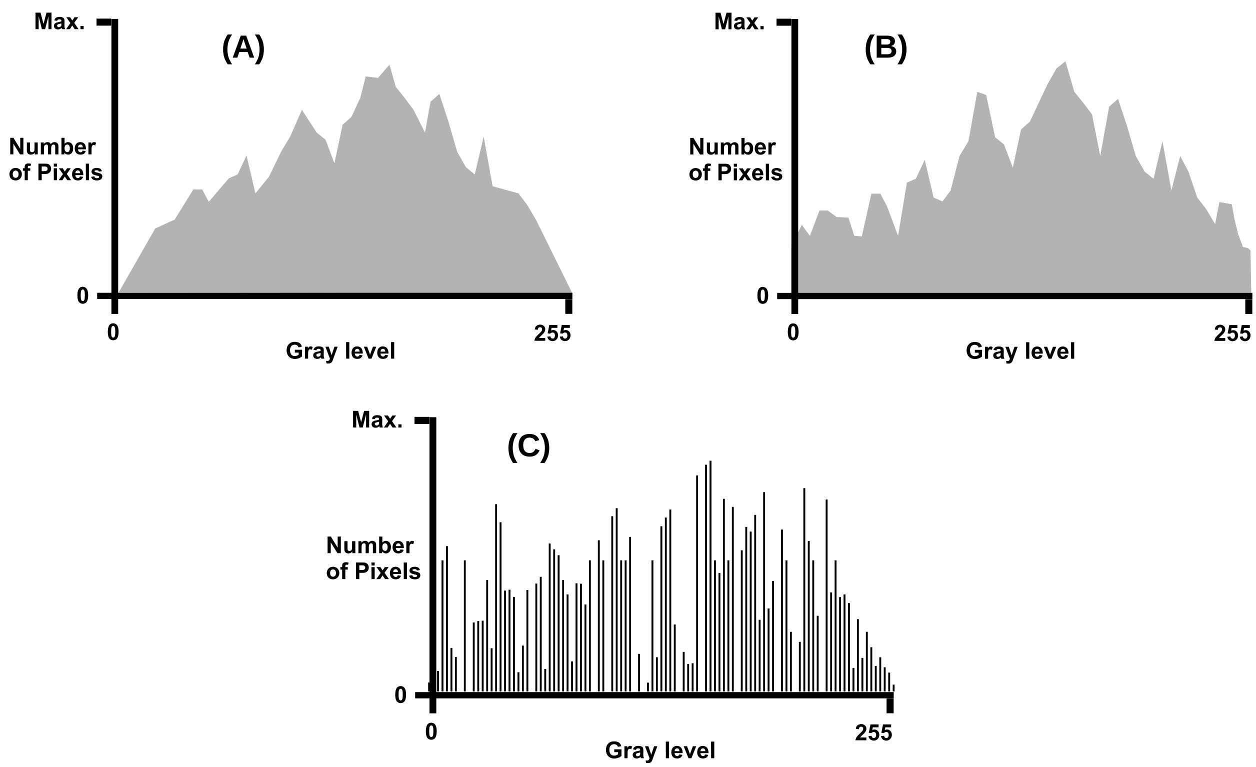


Fig. 3 Histograms of the image files can be used to check whether all digital levels from 0 to 255 are used (A), whether any clipping (loss of shadow and/or highlight details) occurred during scanning (B), or whether the digital values are unevenly distributed as can be the case after image manipulation (C).

Detail and Edge Reproduction (MTF)

To test the detail and edge reproduction of an imaging system, an edge or a sine-wave target should be scanned. In addition, the sine-wave target will make it possible to check for resampling problems.

In the case of document or microfilm scanning, a test target for legibility should also be included.

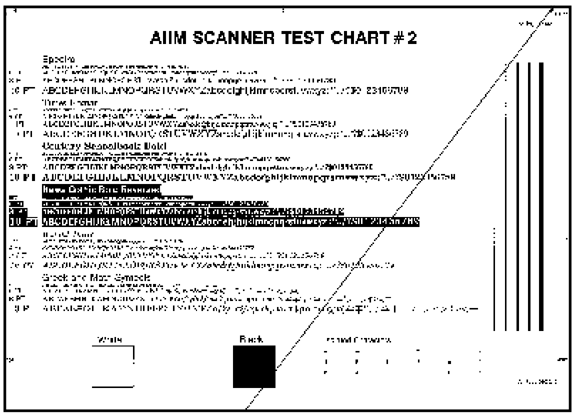


Fig. 4 Upper part of AIIM scanner test chart #2 containing different typefaces for "legibility tests."

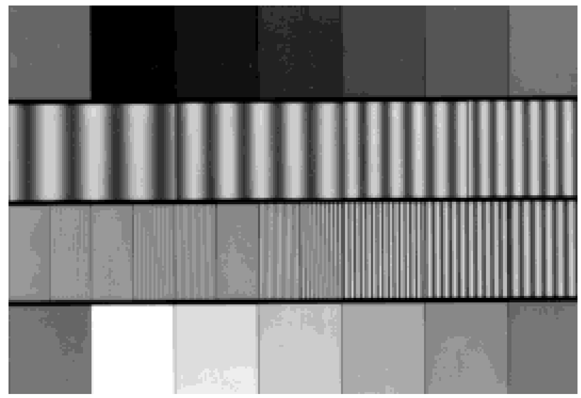


Fig. 5 Sine Patterns sine-wave target. The sine waves in the two center rows of the image are used to calculate the MTF. The MTF shows how much of the modulation that was in the original image made it into the pixel values of the scanned image of the target.

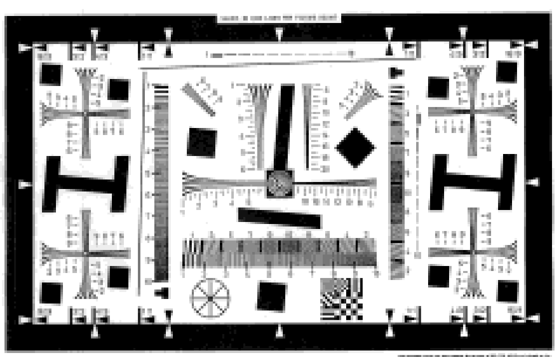


Fig. 6 Resolution test chart developed for electronic still photography. The black bars are used to calculate the modulation transfer function.

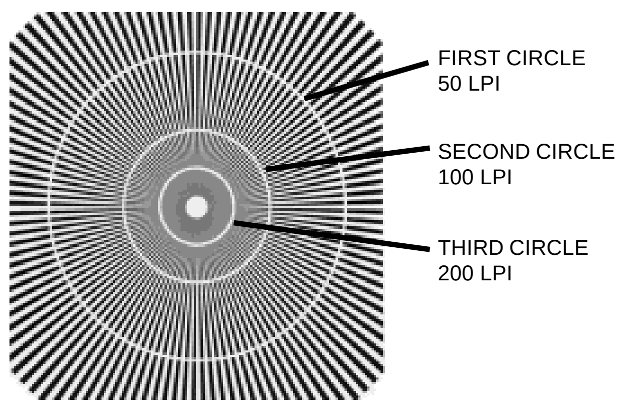


Fig. 7 Bar targets with converging lines, like this star pattern, can be used to visually check the so-called cut-off frequency of the system (i.e., the smallest features that can be resolved), but they cannot be used to get information on how the system is working for all the different frequencies in the image.

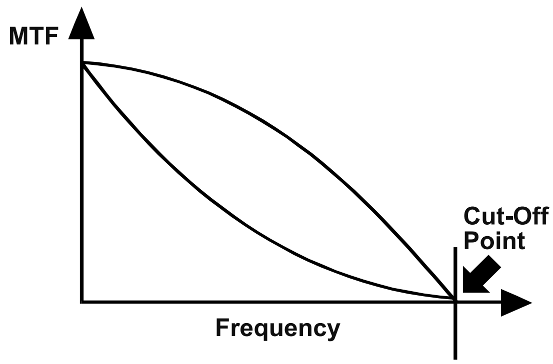


Fig. 8 Graph of the modulation transfer function. The MTF shows the performance of the scanning system over the whole range of frequencies (in the target represented by sine waves that are closer and closer together). The cut-off point of the system represents the highest frequency (the finest image details) that the scanner is able to resolve. An MTF specification that must be met by vendors will have to be worked out.

Noise

The result of the noise test is twofold. First, it shows the noise level of the system, indicating how many bit levels of the image data are actually useful. For image quality considerations, the signal-to-noise ratio (S/N) is the important factor to know.

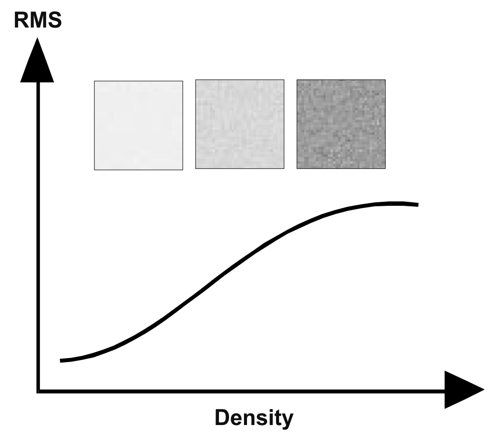


Fig. 9 Noise refers to random variations in electronic imaging systems, represented as a random pattern in the uniform gray patterns. This graph shows the RMS (Root Mean Square), a statistical number representing noise over the density levels of the original image.

Recommended Equipment

To judge images on a monitor, a good monitor/video card combination should be available. The PC should have enough RAM to be able to work efficiently with the highest resolution images. IPI worked with the following equipment:

Nanao FX2-21 Monitor
#9 Imagine Pro 8MB Graphic Card
Monitor calibration tool: Colorific from Sonnetech, Ltd. (included with the monitor suggested above)
Intel Pentium 200Mhz motherboard
64MB of RAM
Adaptec wide SCSI controller
Seagate 4.2GB wide SCSI hard drive
Plextor 6x CD ROM drive

Next Steps

The quality review of scanned images incorporates much more than a specification issue, e.g., how many ppi are required for scanning the documents. Most of the major scanning projects are now going through this phase of setting up a complete framework.

- After the images are scanned, quality control must be applied to ensure that all the images have been scanned correctly (no missing images, numbering correct, no "half images," etc.). Part of the control is done by the vendor, part is done by LC staff. The Library would like to have a framework to be able to contract out the quality control of the scanned images. To assist in creating future RFPs for the vendors, a follow-up project should be designed to define image fundamentals and to investigate the availability of existing software to do the checking.
- Next steps for the NDLP could include a feasibility study using unified targets and trail markers in the three work flows. This would lead to a more exact definition of the software requirements needed to calculate the image parameters.
- Another step should be to compile a glossary and provide training tools for in-house and vendor scanning technicians.

Introduction: National Digital Library Project

To support its growing role in on-line access, the Library has established the National Digital Library Program (NDLP), which has as its primary focus the conversion of historical collections to digital form. During the next five years, the Library plans to convert as many as five million of its more than one hundred million items. The material to be converted includes books and pamphlets, manuscripts, prints and photographs, motion pictures, and sound recordings. Some are in their original forms while others have been reformatted as microfilm or microfiche. As America's national library, the Library of Congress is committed to establishing and maintaining standards and practices that will support the development of the National Digital Library.

History of the Consulting Project

Methodology for Evaluation of Performance and Products of Scanning Service Providers

IPI was contracted to consult on methods to evaluate the performance and products of scanning service providers hired to convert Library materials from paper, flat film, and microfilm to digital images. The Library is first of all looking for guidance for the measurement of spatial resolution. The report shall recommend quality assurance procedures to be used to create measurable images, together with a description of the tools and/or devices needed to measure the outcome of the resulting images. Specifically, the NDLP is seeking technical guidance regarding such concerns as how to perform tests after scanning to measure capture resolution (and tonality) by interpreting or reading test targets or by other means which may be suggested.

Article to Be Delivered

Report of Discussions, Investigations, and Recommendations for Procedures to Be Used, Supported by Scientific Conclusions.

Recommendations for targets and other approaches to measure results for each of the groups listed on the table below, together with recommendations for appropriate devices for the actual measurement itself.

An outcome of the discussions and evaluation may be that new custom targets may need to be devised for the NDLP for effective scanning from the various media.

The Library provided a list of different work flows (see table) for which they needed guidance.

Categories of images: thumbnail (uncompressed TIFF file); 1K x 1K, JPEG highly compressed (20:1/30:1) for viewing on the screen; 3K x 3K, JPEG slightly compressed (4:1/5:1) for reproduction purposes

Source	Device	Image Type	Resolution, Scale, etc.
Document Paper original Archetype: 8 1/2 x 11-inch document	Flatbed scanner	Bitonal	300 dpi
			600dpi
		Grayscale or color	150 dpi
			300 dpi
	Camera or other overhead device	Bitonal	300 dpi
			600 dpi
		Grayscale or color	150 dpi
			300 dpi
Pictorial item Reflected light Archetypes: 8 x 10-inch print Item on 11 x 14-inch board with significant writing to the edge	Flatbed scanner	Grayscale or color	Image in 1K x 1K-pxl window
			Image in 3K x 3K-pxl window
	Camera	Grayscale or color	Image in 1K x 1K-pxl window
			Image in 3K x 3K-pxl window
	Via intermediate (typically film)	Grayscale or color	Image in 1K x 1K-pxl window
			Image in 3K x 3K-pxl window
Pictorial item Transmitted light Archetypes: 8 x 10-inch negative 4 x 5-inch transparency 35mm slide	Flatbed scanner	Grayscale or color	Image in 1K x 1K-pxl window
			Image in 3K x 3K-pxl window
	Camera	Grayscale or color	Image in 1K x 1K-pxl window
			Image in 3K x 3K-pxl window
	Via intermediate (typically film)	Grayscale or color	Image in 1K x 1K-pxl window
			Image in 3K x 3K-pxl window
Microfilm Archetype: 35mm film containing images of documents on letter-or legal-size paper	Microfilm scanning device	Bitonal	Produce image to print to typing paper
		Grayscale or color	

Meeting in Washington (December 15th and 16th)

The Library was seeking answers to questions related to spatial resolution in scanning documents, books, photographs, and microfilm. However, during our stay more and more questions related to other areas of image quality came up. The following report will concentrate on the issue of resolution, but IPI also proposes a framework to deal with other aspects of image quality. Especially in the case of photographs, good tone reproduction is crucial for a good digital reproduction of the original images.

Notes from Meeting

Scanning photographs calls for the most rigid approach to image quality. It requires a quality framework that addresses all the different points that came up during the discussions. Resolution, tone reproduction, and monitor calibration are the most critical ones up to now. Past scanning projects have shown that interaction with vendors can be problematic because a clear common language is lacking.

Legibility is the main problem in scanning microphotographic materials and paper documents. In both cases, illustrations may pose problems. Paper documents often contain halftone images that pose a problem for scanning. For microfilms, the quality of halftone illustrations is dependent on good microfilming techniques and on the scanning process.

Issues in Scanning of Books

The following points were discussed:

- Legibility is the main criterion for judging the quality of the digitized documents.
- Guidelines for scanning technicians in existing contracts have been worked out to assure a certain level of quality, but new RFPs shall have better-defined requirements.
- Practical or "doable" solutions are desired—nothing too complicated.
- The Library wishes to create a vendor-selection process based on objective tests. How can spatial resolution be measured? How can you be sure that you get the resolution you ask for?
- Up to this point spatial resolution has not been a problem in the task of scanning documents. However, in the process of scanning books, a lot of points *do* pose problems, like the handling of the books, finding the right threshold for the digital values that differentiate the background of the page from the text, etc.
- The quality inspection for vendor selection shall be a pass/fail process.
- Requirement: the system shall deliver an image with specified ppi. In the case of

fonts, the requirement is whether a font is resolvable or not.

- In scanning Civil War photos (11 x 7 inches mounted on boards approximately 11 x 14 inches in size), there is some fine text on the mounts that should be readable.
- For pictorial images, the screen appearance is the crucial point, meaning that the usual output medium is the CRT screen.
- For paper documents, a laser printer is the usual output medium by which the users will judge the quality.
- Printed halftone reproductions are a problem for the scanning process. In order to deal with the problem of moiré, the images must be dithered. So far, a special algorithm from Xerox has proved to be best for that application, but the algorithm is only available as part of special scanning hardware.
- QC procedures that are already in place for illustration images:
    - File names are reviewed.
    - Image defects (e.g., obvious defects such as half images, dirt, dust, black or white borders, cropping) are looked for.
    - For printed halftones, the lightness of the image is subjectively judged.
- Deciding whether or not an image needs to be dithered is sometimes left up to the discretion of the scanning operator. Experience of the operator is very important in determining the quality of the scans.
- Software tools in use: PhotoStyler, View Director, Docu Viewer, HiJaak Pro Image Viewer

Microfilm Scanning Issues

The following is a summary of the points discussed.

- Very few companies offer microfilm scanning services for special documents. The scanning of these materials requires special handling, higher standards, and greater quality control than the scanning of record materials for government and business. Multiple exposures, targets, and frequent changes in reduction ratio, orientation, and document size are common to preservation microfilm. In addition, the original materials often contain illustrations that need to be captured in halftones. Besides the possibility of dealing with scanning halftones, legibility is the main quality issue when scanning preservation microfilms.

Photo Scanning Issues

The following is a summary of the points discussed.

- According to a strict guideline that must be observed in handling some of the photographs, originals must not be flipped over (physically). This imposes some restrictions on the scanning devices that can be used. Therefore, the use of a digital camera (like the Kontron ProgRes) in a reproduction setup might be the appropriate way to go.
- The digital images will be used as references, not as preservation surrogates, meaning that a medium level of quality is required. The amount of storage needed for the images is a major concern.
- Text on posters and images should be readable.
- Monitor calibration is a major concern when looking at images.
- Daguerreotypes: security issue, high-quality digital image wanted. The daguerreotype collection project showed a lot of problems in the scanning process and the digital images obtained were not satisfactory.

Another issue came up while browsing through the collection: What should be done with *stereo images*?

It might be an interesting project to present part of the stereo image collection to the public in form of anaglyphs (two superimposed images of different colors, such as red and green, representing slightly different angular views of the same subject. When viewed through filters of the same colors, each eye sees the corresponding left or right image, but the viewer perceives a single fused three-dimensional image). There exists a variety of programs used in microscopy that could be used (with certain changes) to prepare the stereo images. Special red-green glasses would be needed for viewing the images.

History of Scanning Projects in the Photographic Department

Many different approaches have been used for scanning. What is needed is a "bigger picture" that creates a standardized and documented set of digital images. What approaches should be taken for calibrating monitors, "standardizing" viewing images, etc.?

Once this framework is set up, one of the next steps might be to develop standards for the training of scanning technicians.

How to articulate questions for the vendors is another issue that would become clearer if a proper framework including all different scanning parameters were in place.

Introduction to Image Quality in Digital Imaging

As digital imaging emerges from its infancy, more and more libraries and archives are starting digital projects. Unfortunately, questions of image quality are often neglected at the beginning of such projects. Despite all the possibilities for endless copying, distributing, and manipulating digital images, image quality choices made when the files are first created have the same “finality” that they have in conventional photography. These choices will have a profound effect on project cost, value of the final project to researchers, and usefulness of the images as preservation surrogates. Image quality requirements therefore should be established *before* a digitization project starts.

The creation of large digital image collections is not likely to be attempted more than once a generation. This means that it had better be done right the first time, so being aware of the technical nature of the digital images produced is quite important. Building high-quality digital image collections requires a long-term strategy for developing digital assets of lasting value.

Image quality has to be determined separately for digital images that result from reformatting photographic, microphotographic and paper documents. For the two latter categories, image quality will mean, above all, legibility of all the significant data. For photographs, image quality is determined by tone and color reproduction, detail and edge reproduction, and noise.

The main quality issue for reformatted paper documents is legibility. This is a twofold problem: a high enough spatial resolution must be chosen to capture the details of the characters and the correct threshold must be chosen to be able to distinguish between foreground and background.

The Library’s functional image requirements for converting microfilms to digital files are as follows:

> It is required the digital images contain all of the significant data in the microfilm image. Success in retaining significant data will be determined by the legibility of the materials to be digitized under performance of this contract; i.e., when all the words, drawings or other markings, or musical notes can be read in the digital image as could be read in the document on the microfilm.

The high level of image quality in original photographs sets a very high standard for successful reformatting projects. One reason why there is such high image quality inherent

in original collection materials is because large formats were quite common, even for amateur photographers, until the 1960s. Many photographs represent work of outstanding quality and information content.

In the context of collections in libraries and archives, the success or failure of a digital image database system ultimately depends on whether or not it really enhances access or promotes the preservation of the collection. This does not necessarily mean that images must be of the highest possible quality to meet the needs of the institutions. The way in which the digital files are to be used should dictate how high image quality should be. It should be remembered that the higher the quality, the more expertise, time, and cost is likely to be needed to generate and deliver the digital image.

The following are three examples of digital image quality criteria for photographic images:

- *The digital image is used only as a visual reference in an electronic data base*. The required digital image quality is low, both in terms of spatial and brightness resolution content. The display is usually limited to a screen or low-resolution print device. Exact color reproduction is not critical. Additionally, images can be compressed to save storage space and delivery time. Using duplicates of the originals and a low-resolution digitizing device will be sufficient for these applications.
- *The digital image is used for reproduction*. The quality requirements will depend on the definition of the desired reproduction. Limiting output to certain spatial dimensions will facilitate the decision-making process. The same applies to tonal reproduction. Currently, most digitizing systems will only allow an 8-bit-per-color output which, if not mapped correctly, does not always allow for precise tonal and color reproduction of the original.
- *The digital image represents a "replacement" of the original in both spatial and tonal information content*. This goal is the most challenging to achieve given today's digitizing technologies and cost. The information content in terms of pixel equivalency varies from original to original. It is defined not only by film format, but also by emulsion type, shooting conditions, and processing techniques. Additionally, 8-bit-per-color scanning device output might be sufficient for visual representation on today's output devices, but it might not capture all the tonal subtleties of the original. On the other hand, saving "raw" scanner data of 12 or 16 bits per color with no tonal mapping can create problems for future output if the scanner characteris-

tics are not well known and profiled. Ultimately, "information content" has to be defined, whether based on human visual resolving power, the physical properties of the original, or a combination of both.

Each of the above quality criteria requires a different approach to the digitization process and a different level of resources. The challenge is that not just one but all criteria might be required to digitize one collection of photographs.

Spatial resolution of a digital image, i.e., how many details an image contains, is usually given by the number of pixels per inch (ppi). Spatial resolution of output devices, such as monitors or printers, is usually given in dots per inch (dpi).

To find the equivalent number of pixels that describe the information content of a specific photographic emulsion is not a straightforward process. Format of the original, film grain, film resolution, resolution of the camera lens, f-stop, lighting conditions, focus, blur, and processing have to be taken into consideration to accurately determine the actual information content of a specific picture.

Given the spatial resolution of the files, how big an output is possible from the available file size? The relationship between the file size of a digital image, its total number of pixels, and consequently its maximum output size at different spatial resolutions can be analyzed mathematically. The distinction has to be made between continuous-tone and halftone output. Going into greater detail is beyond the scope of this report, but such information could be part of a glossary for scanning technicians.

For optimal continuous tone output the ratio between output dots and image pixels

Film Type	Format	Equivalent Number of Pixels
ISO 25-64 (very fine grain)	35mm	12.5 million
	120	51 million
	4 x 5	180 million

Film Type	Format	Equivalent Number of Pixels
ISO 200-500 (medium grain)	35mm	4.2 million
	120	17.6 million
	4 x 5	61 million

Approximate pixel equivalencies for various film types and formats.

should be 1:1. In case of printing processes that require halftone images, 1.5:1 oversampling (ppi of digital file is higher than lpi=lines per inch of output) is needed.

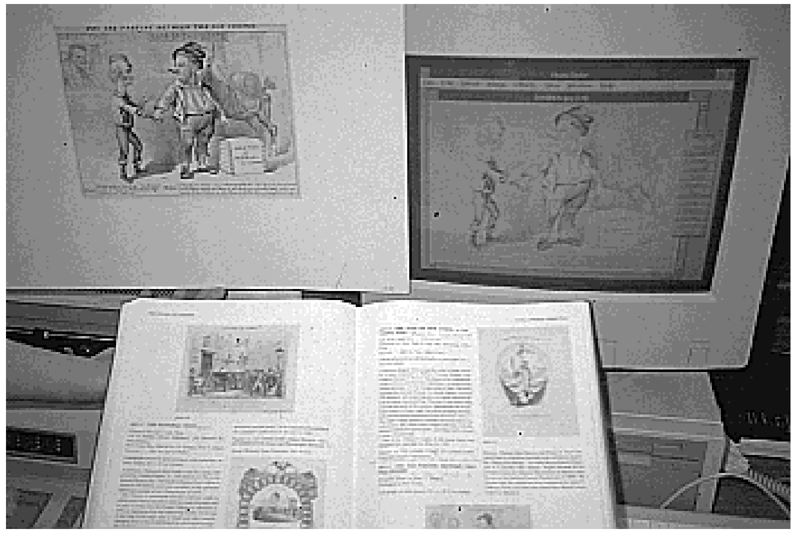


Fig. 10 Comparison of original printed reproduction and digital image on monitor. A standardized environment with calibrated monitors and dim room illumination is needed for subjective image quality evaluation.

Definition of Image Quality

There are no guidelines or accepted standards for determining the level of image quality required in the creation of databases for access or preservation of photographic, microphotographic, or document collections. As a result, many institutions now starting their scanning projects will be disappointed sooner or later, because their choices did not take into account future changes in the technology. However, nobody knows what technology will be available in a few years, and choosing the right scanning parameters is a task that still needs to be researched. One problem is that the cycle of understanding image quality is just beginning for the new imaging technologies.

For documents the most important quality issue is legibility. A. Kenney states in her report:*

> Quality Index (QI) is a means for relating resolution and text legibility. While type size might be the most important factor in legibility, other factors should be taken into consideration, including typeface; the use of italics and boldface; pitch; line width; interlinear spacing; counter; background color; printing surfaces; the degree of fading, damage, and acid migration; and the quality of the original document. Whether it is used for microfilming or digital imaging, QI is based on relating text legibility to system resolution, i.e., the ability to capture fine detail. QI may be used to forecast the levels of image quality—marginal (3.6), medium (5.0), or high (8.0)—that will be consistently achieved on the use copy. The applicability of standards established for microfilming—an analog process—to image quality for material converted via digital technology may be open to some debate. While acknowl-

*A. Kenney and S. Chapman, *Digital Resolution Requirements for Replacing Text-Based Material: Methods for Benchmarking Image Quality.*

> edging differences between digital and analog capture, the C10 Committee developed a Digital Quality Index formula that is derived from the Classic Quality Index formula used in the micrographics industry. Both formulas are based on three variables: the height of the smallest significant character in the source document, the desired quality to be obtained in the reformatted version, and the resolution of the recording device.

It should be kept in mind that scanning from an archive is different from scanning for prepress purposes. In the latter case, the variables of the process the scanned image is going through are known, and the scanning parameters have to be chosen accordingly. If an image is scanned for archival purposes, the future use of the image is not known, and neither are the possibilities of the technology that will be available a few years from now. This leads to the conclusion that decisions concerning the image quality of the archival image scans are very critical.

Image quality is usually separated into two classes:

- *Objective* image quality is evaluated through physical measurements of image properties. In the case of digital imaging this is achieved with special software evaluating the digital file.
- *Subjective* image quality is evaluated through judgment by human observers.

The historical emphasis on image quality has been on image physics (physical image parameters), also called objective image evaluation. Psychophysical scaling tools to measure subjective image quality have been available only for the last 25 to 35 years.

What is a psychometric scaling test? Stimuli which do not have any measurable physical quantities can be evaluated by using psychometric scaling methods. The stimuli are rated according to the reaction they produce on human observers. Psychometric methods give indications about response differences. There are three established psychometric methods which provide a one-dimensional scale of response differences: the method of rank order, the method of paired comparison, and the method of categories. The method of rank order lets observers order the samples. In a paired comparison test, observers are asked to choose between two stimuli based on some criterion. The method of categories requires observers to sort stimuli into a limited number of categories; these usually have useful labels describing the attribute under study (e.g., excellent, very good, good, fair, poor, unsatisfactory).

Technical pictorial image quality parameters can be assessed by considering the follow-

ing four basic attributes:

Tone reproduction. Refers to the degree to which an image conveys the luminance ranges of an original scene (or of an image to be reproduced in the case of reformatting). It is the single most important aspect of image quality. Tone reproduction is the matching, modifying, or enhancing of output tones relative to the tones of the original document. Because all of the varied components of an imaging system contribute to tone reproduction, it is often difficult to control.

Detail and edge reproduction. Detail is defined as relatively small-scale parts of a subject or the images of those parts in a photograph or other reproduction. In a portrait, detail may refer to individual hairs or pores in the skin. Edge reproduction refers to the ability of a process to reproduce sharp edges.

Noise. Noise refers to random variations associated with detection and reproduction systems. In photography, granularity is the objective measure of density nonuniformity that corresponds to the subjective concept of graininess. In electronic imaging, it is the presence of unwanted energy in the signal. This energy will degrade the image.

Color reproduction. Equivalent color reproduction is defined as reproduction in which the chromaticities and relative luminances are such as to produce the same appearance of color as in the original scene.

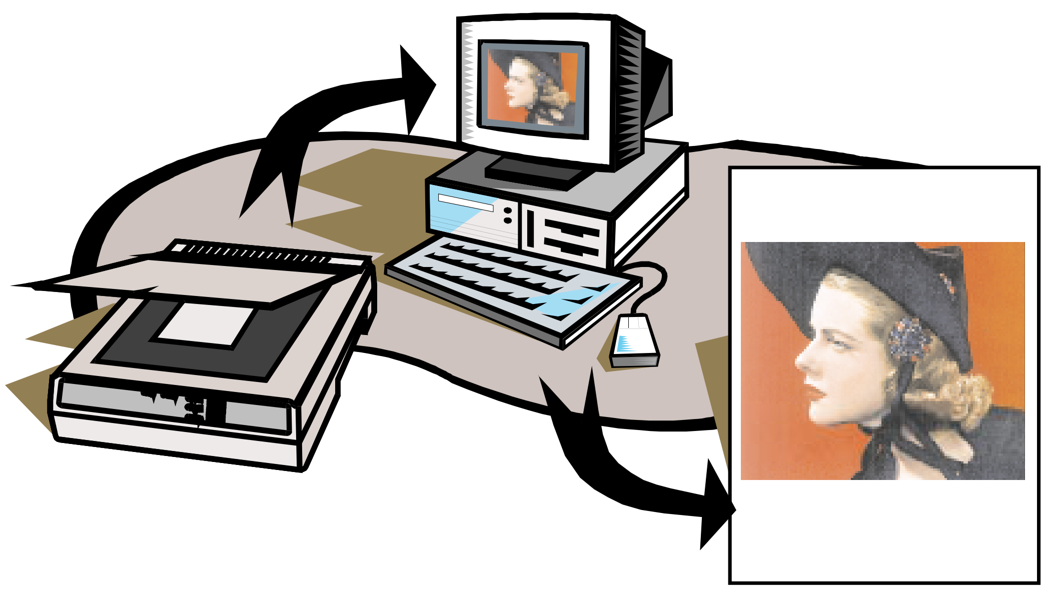


Fig. 11 Color management ensures consistent colors through the whole digital chain, from scanner to monitor to printer.

Proposed Framework (Excluding Color and Subjective Quality Tests)

The approach to image quality will be different for the three main image categories. Spatial resolution applies to all categories. In the case of microfilm scanning, calculating MTF does not make sense for bitonal mode.

For paper documents and microfilms, where legibility is usually the main quality issue, special targets to calculate the QI are needed.

For the first approach to pictorial image quality, this report will concentrate on three objective parameters:

- Tone reproduction
- Sharpness (modulation transfer function)
- Noise

We will try to set up a framework that will facilitate the objective measurement of these parameters (see below). Discussions with various people from the field have shown that there is high interest in having a software tool to easily measure these objective image parameters.

This approach is the one taken by two projects looked at by IPI. Both projects scan targets—one, the Sine Wave Pattern test target and the other, the Resolution Test Chart for electronic still photography which is under development—and interpret the digital images with a software program that automatically calculates some parameters.

The issue of color will be excluded from this framework. Nevertheless, IPI thinks it is very important for the Library to include some form of color management system for future handling of color originals.

The following are some issues coming up in setting up the framework. Some apply to all three work flows, some apply more to pictorial images (see "Factors to Consider in Pictorial Digital Image Processing," J. Holm).

The flexibility of digital processes makes them ideal for producing aesthetically optimized images on a variety of output media, from monitors to snapshots to press sheets. However, this same flexibility makes the optimization difficult and complicated. In the case of digital photography for example, the quality of digital photographs is typically inferior to that of conventional photographs. This is due in part to the limitations of current image capture and output devices, but incorrect or incomplete processing is also a major factor.

There are three reasons why a pictorial digital image processor may not be able to produce an optimal photographic rendition: lack of expertise, lack of information, and lack of time. Designers of conventional photographic systems are aware of this and design

systems that optimize photographic renditions to a large extent automatically.

Digital photography has the potential to optimally render every scene. A unified approach to the problem is needed, together with an understanding of its complexity. Efforts are under way in industry to automate the task of optimal image reproduction with the use of a so-called Automated Pictorial Image Processing System (APIP). One of the major areas to be defined is the image-associated data required for APIP. These are the same data that are considered during the manual processing of images.

Standardized approaches and data forms are required for interchangeability. Manufacturers are strongly encouraged to facilitate the complete transfer of the information associated with the image files. To quote M. Ester in "Specifics of Imaging Practice":

> If I see shortcomings in what we are doing in documenting images, they are traceable to the lack of standards in this area. We have responded to a practical need in our work, and have settled on the information we believe is important to record about production and the resulting image resource. These recording procedures have become stable over time, but the data would become even more valuable if there was broad community consensus on a preferred framework. Compatibility of image data from multiple sources and the potential to develop software around access to a common framework would be some of the advantages.

The following outlines some of the points that have to be considered when going through the digital image chain from image capture (scanning) to output; the highest resolution files representing the best quality of the reformatting project can be considered the "digital masters." Great care should be taken in producing them; they contain the value of the digital collection and require an intensive quality review.

Digital Capture

M. Ester proposes the following two approaches for digital capture for a consistent conversion of a collection into the digital environment. But both of his approaches use a conventional duplicate as an intermediate product:

> *Matching to film*. Under this logic the goal is to make the digital image look the same as the photographic medium. In favorable circumstances, with color control bars in the photograph, one can take densitometer readings from the film, and knowing their digital counterparts, use these values as references for the scanned image. This process can be applied very consistently to achieve a record of the film.
>
> *Matching to the scene*. The logic of this process says that if we have a color bar in a photograph and the digital values of the target are known, then as the color bars in a

scanned image are adjusted to their correct values the rest of the image is matched to these controls as well. We call this matching the "scene," because it represents the photographic scene at the moment the photograph was taken.

Processing for Storage

The best way to store image data is to store the raw capture data. Subsequent processing of this data can only reduce the information contained, and there is always the possibility that better input processing algorithms will become available further on. Input processing removes the effects introduced by the scanning process. The image data archived should therefore be the raw data, along with the associated information required for processing, whenever possible. This data may be compressed to some extent using lossless compression, but in many cases it may also be desirable to store image data which has undergone some processing to reduce file size. For example, the raw data may be linear and/or contain unoccupied levels, meaning that not every digital level actually contains a pixel of the image. Perception is quite nonlinear, and 12-bit linear data can be reduced to 8-bit nonlinear data with no perceptual loss if the reduction lookup table (LUT) adapts to the dynamic range of the data.

Processing for Viewing

Processing for viewing is a type of output processing applied to produce images of good viewing quality. It is possible to design viewer software that can take image files which have undergone input processing and process them for output on a monitor.

Brightness Resolution

The most widely used values for bit-depth equivalency of digital images is still 8 bits per pixel for monochrome images and 24 bits for color images. These values are reasonably accurate for good-quality image output. Eight bits per channel on the input side is not sufficient for good-quality scanning of diverse originals. To accommodate all kinds of originals with different dynamic ranges, the initial quantization on the CCD side must be larger than 8 bits.

Tone and color corrections on 8-bit images should be avoided. The existing levels are compressed even further, no matter what kind of operation is executed. To avoid the loss of additional brightness resolution, all necessary image processing should be done on a higher bit-depth file, and requantization to 8-bit images should occur after any tone and color corrections.

Correct brightness resolution is as much a part of overall digital image quality as is spatial resolution. Neither one can be neglected.

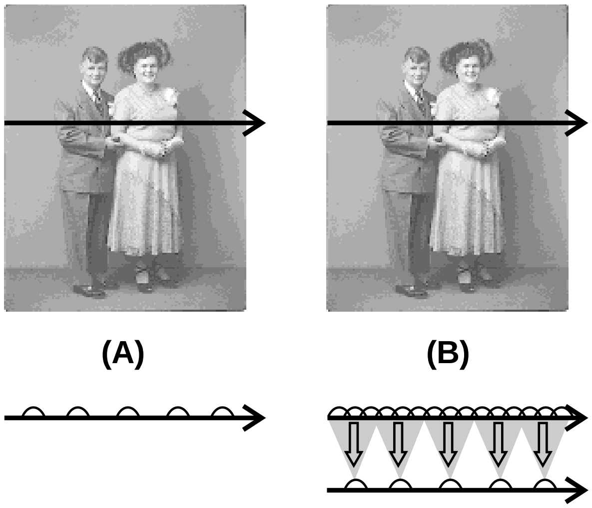


Fig. 12 The number of sampling points within a given distance is referred to as the device's digital resolution. In case (A) the digital resolution is low, and not all the image information will be included in the digital file. Case (B) is sampled with a higher resolution. A low-resolution derivative that is calculated from this high-resolution file (with a resampling algorithm) will have a higher quality than the image originally scanned at low resolution. This is because in case (B) all of the image information is included in the original file.

What is Digital Resolution?

Why do we measure resolution? We do so, first, to make sure that the information content of the original image is represented in the digital image and, second, to make sure that the scanning unit used to digitize the image is in focus.

Unlike photographic resolution, digital resolution does not depend on visual detection or observation of an image. Digital resolution is calculated directly from the physical center-to-center spacing between each sample or dot. This spacing is also called the sampling interval.

The number of sampling points within a given distance (usually an inch) is referred to as the device's digital resolution, or pixels per inch (ppi). Digital resolution quantifies the number of sampling dots per unit distance while photographic resolution quantifies observed feature pairs per unit distance as in line pairs per millimeter (lp/mm).

Translating between units of classical resolution and digital resolution is simply a matter of "two." Dividing digital resolution values in half will yield units that are equivalent to photographic resolution. But there are conceptual differences between the two that have to be kept in mind when using digital resolution. Aliasing is the primary problem to be taken into account here; furthermore, a misregistration between image details and image sensors may give the impression that a certain device has less resolution than it actually has.

If the sampling interval is fine enough to locate the peaks and valleys of any given sine wave, then that frequency component can be unambiguously reconstructed from its sampled values. Aliasing occurs when a wave form is insufficiently sampled. If the sampling is less frequent, then the samples will be seen as representing a lower-frequency sine wave.

The most noticeable artifact of aliasing is high spatial frequencies appearing as low spatial frequencies. After the wave form has been sampled, aliasing cannot be removed by filtering.

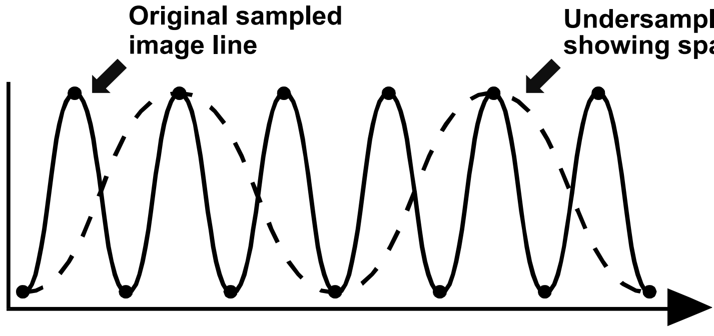


Fig. 13 Aliasing occurs when a wave form is insufficiently sampled (dotted line). The samples will show up as representing a lower-frequency sine wave (i.e., the waves are further apart).

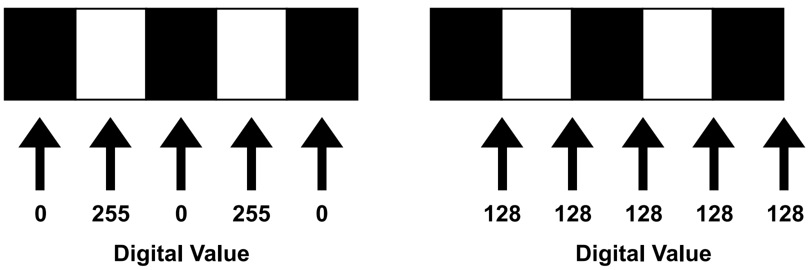


Fig. 14 Misregistration between the detectors and the lines of the target by half a pixel can lead to the situation where the black-and-white lines of the original cannot be resolved and will look like a gray field in the digital image (all the digital values are the same, i.e., 128).

In an ideal scan, the detectors and the lines of the target are perfectly aligned. The concept of misregistration can be easily shown by scanning a bar target. The detectors will only sense the light intensity of either the black line or the white space. If there is a misregistration between the centers of the lines and spaces relative to the detector centers, say by half a pixel, the outcome is different. Now each detector "sees" half a line and half a space. Since the output of every detector is just a single value, the intensities of the line and the space are averaged. The resulting image will therefore have the same digital value in every pixel. In other words, it will look like a grey field. The target would not be resolved. Therefore, the misregistration manifests itself as a contrast or signal loss in the digital image which affects resolution. Since it is impossible to predict whether a document's features will align perfectly with the fixed positions of a scanner's detectors, more than two samples per line pair are required for reliable information scanning.

How Do You Measure Digital Resolution?

The fundamental method for measuring resolution is to capture an image of a suitable test chart with the scanner being tested. The test chart must include patterns with sufficiently fine detail, such as edges, lines, square waves, or sine-wave patterns.

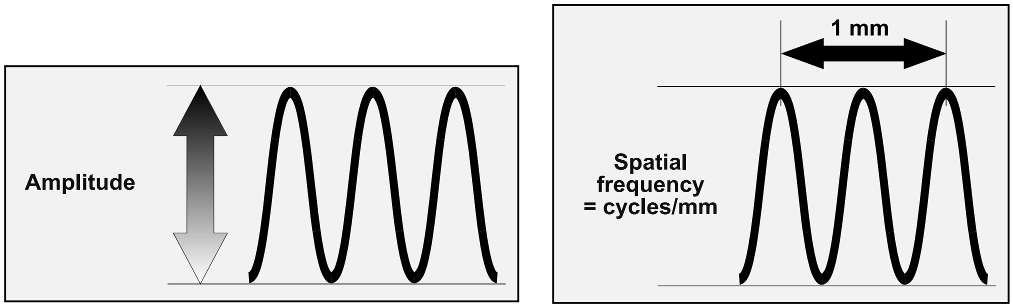


Fig. 15 A wave is characterized by its amplitude and its spatial frequency.

The MTF

The best overall measure of detail and resolution is the MTF (modulation transfer function). MTF was developed to describe image quality in "classical" optical systems. The MTF is a graphical representation of image quality that eliminates the need for decision-making by the observer. The test objects are sine-wave patterns. The MTF is a graph that represents the image contrast relative to the object contrast on the vertical axis over the range of spatial frequencies on the horizontal axis, where high frequency in the test target corresponds to small detail in an object (see Fig. 20). MTF is complicated to measure in images on photographic materials, but it is relatively easy to measure in digital images.

$$\text{Modulation Transfer Function} = \frac{\text{Output Modulation}}{\text{Input Modulation}} \quad \left(\text{across a range of frequencies}\right)$$

If MTF is measured for a sampled-data system, the measured MTF will depend on the alignment of the target and the sampling sites. An average MTF can be defined, assuming that the scene being imaged is randomly positioned with respect to the sampling sites.

There are two approaches to defining the MTF of an imaging system. One is to use a sine-wave pattern, the other is to use a slanted edge. In the latter case, pixel values near

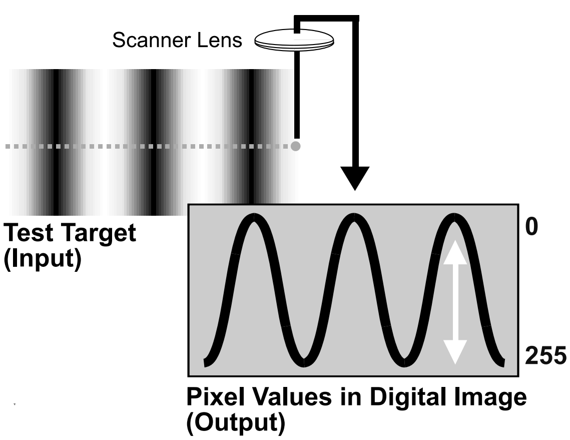


Fig. 16 The sine waves of the test target are scanned and translated into digital values. If you were to measure how dark or light the image was at every point along a line across the bars, the plot of these points would be a perfect sine wave. If the digital values along the same line are plotted, the resulting figure is also a sine wave.

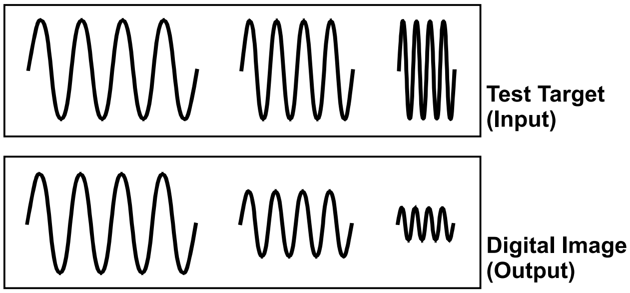


Fig. 17 Input modulation/output modulation

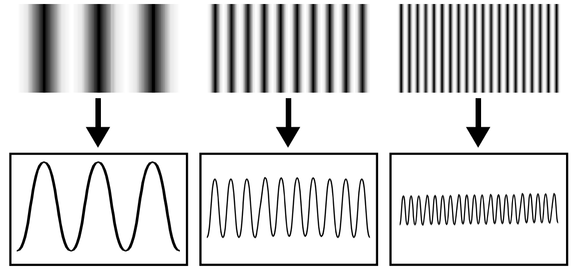


Fig. 18 As the bars of the sine-wave target get closer together at higher frequencies, the modulation (i.e., variation from black to white) that is recorded by the scanner gets smaller and smaller.

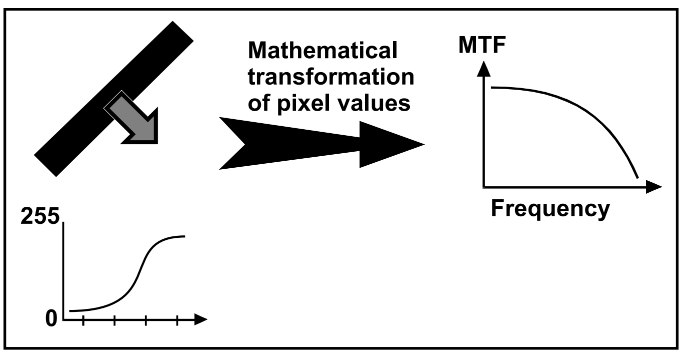


Fig. 19 Calculating the MTF using the moving knife-edge method. Pixel values across a slanted edge are digitized and, through a mathematical transformation of these values into the Fourier domain, the MTF of the system can be calculated.

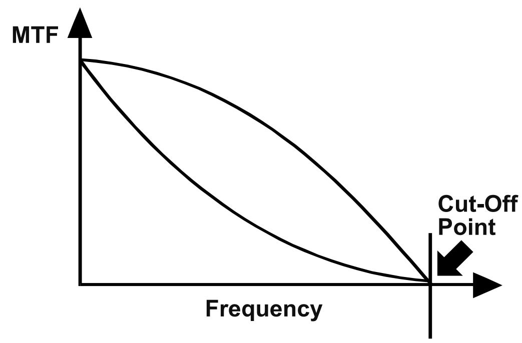


Fig. 20 Graph of the MTF. The MTF shows the performance of the scanning system over the whole range of frequencies (in the target represented by sine waves that are closer and closer together). The cut-off point of the system represents the highest frequency (the finest image details) that the scanner is able to resolve.

slanted vertical and horizontal black-to-white edges are digitized and used to compute the MTF values. The use of a slanted edge allows the edge gradient to be measured at many phases relative to the image sensor elements, in order to eliminate the effects of aliasing. (This technique is mathematically equivalent to performing a "moving knife-edge measurement.")

In the case of bitonal scanning (e.g., microfilm) it does not make sense to calculate the MTF. In this case, the QI approach using test targets with fonts may be used. To qualify the system, running the scanner in gray scale mode might be considered.

The QI approach may also be used to check whether Photo CD quality is good enough for 11 x 14-inch originals (Civil War photos, 11 x 7 inches mounted on boards approxi-

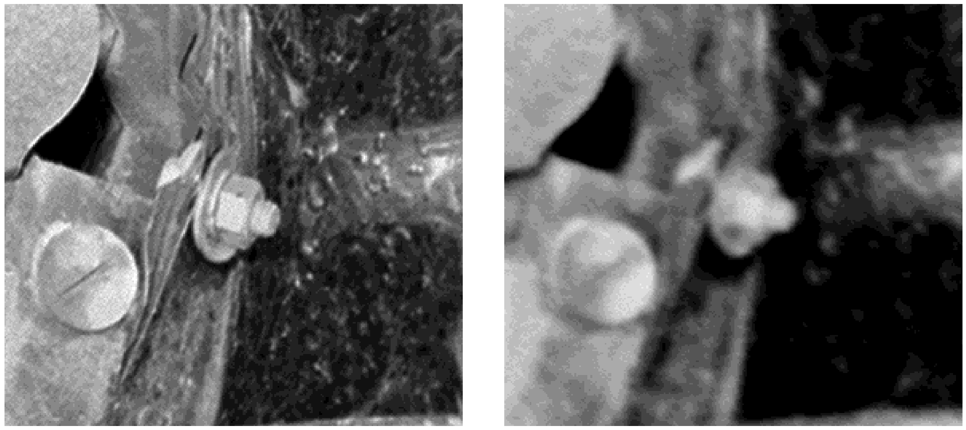


Fig. 21 Scanning from original or intermediate? Scan on left is from an 8x10 original negative, scan on right is from a 35mm intermediate.

mately 11 x 14 inches in size, that include fine text).

A recommended approach is to take a 35mm photograph from the original and scan it onto a Photo CD, then make a legibility test.

In addition, if a reformatting step onto film is involved, film type differences might introduce problems in trying to keep the color consistent.

An earlier project conducted in part at IPI (together with Stokes Imaging) showed that if it is possible to scan directly from the original the results are better.

Targets to Use

What kind of targets can be used to measure digital resolution? Usually, the targets designed for measurement of photographic resolution are used. These “bar targets” all have the problems of aliasing and misregistration in the digital image. However, bar targets can be used to check resolution visually and obtain the “cut-off frequency,” e.g., the highest frequency the system is able to resolve. Visually checking bar targets is not an easy task; the observer must know what to look for.

Therefore, to measure digital resolution of sampling devices another approach has to be taken using slanted edges or sine-wave patterns.

The scanned test target should be evaluated with a software program (to be developed). This idea has received very positive reactions from the various people contacted about it. Having an objective tool to compare different scanning devices will be more and more important. Up to now scanner manufacturers usually have used their own software when determining the spatial resolution or MTF of their systems.

Fig. 22 IEEE Std 167A-1987 facsimile test chart designed for use with facsimile machines. It is produced photographically and includes gray-scale bars, test, rules, and a continuous-tone image. It also incorporates traditional line-pair patterns.

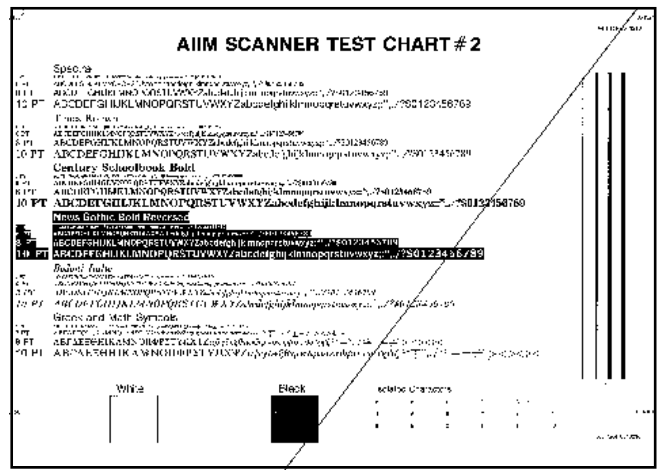


Fig. 23 Upper part of AIIM scanner test chart #2 containing different typefaces for "legibility tests."

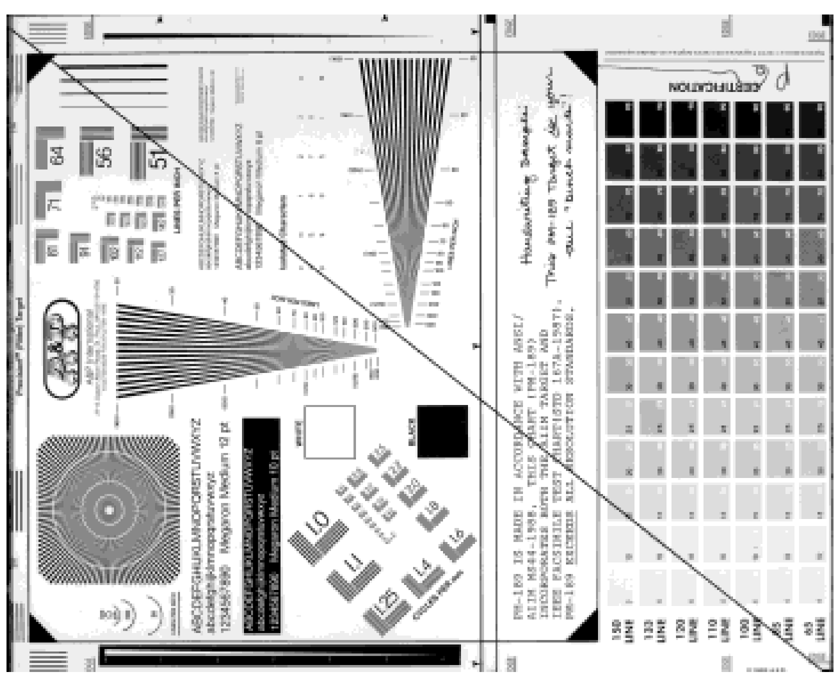


Fig. 24 Scanner test target PM-189. It incorporates both the AIIM target and the IEEE facsimile test chart.

Federal Reserve System

Quality Index Test Image

Point Size	Quality Index			Lower Case "e"	
	High	Medium	Marginal	Height	Sample
6				1.0 mm	
7				1.2 mm	
8				1.3 mm	
9				1.5 mm	
10				1.7 mm	

Fig. 25 Quality Index test image to calculate QI (Picture Elements, Incorporated).

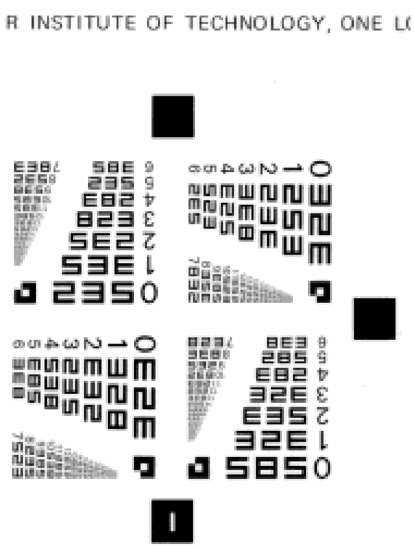


Fig. 26 RIT Alphanumeric test target. It consists of lines of block letters. During inspection, an observer must recognize letters, rather than detect resolved line pairs. Can be used for "legibility tests."

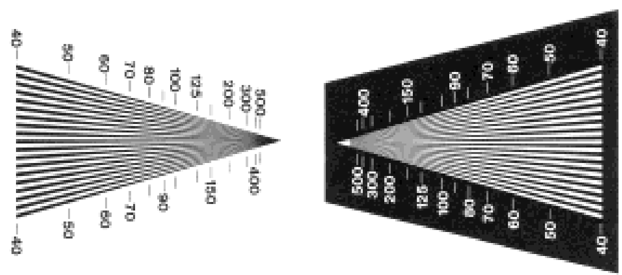


Fig. 27 High-contrast bar targets with converging lines can be used to visually check the so-called cut-off frequency of the system (i.e., the smallest features that can be resolved), but they cannot be used to get information on how the system is working for all the different frequencies in the image (Picture Elements, Incorporated).

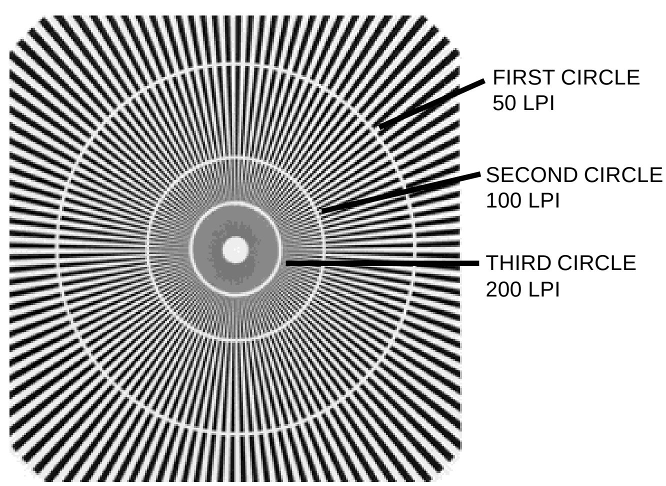


Fig. 28 Bar targets with converging lines, like this star pattern, can be used to visually check the so called cut-off frequency of the system, i.e., the smallest features that can be resolved, but they can not be used to get information on how the system is working for all the different frequencies in the image.

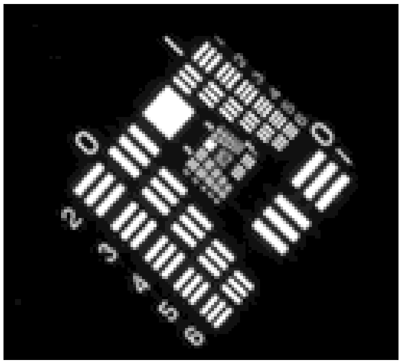


Fig. 29 USAF Resolving Power test target. The table below contains the number of lines per millimeter related to the group number (number above a group of line pairs) and element numbers (number on the side of the line pairs) on the target. In order to avoid sampling effects, the target should be placed at an angle of 45 degrees to the CCD elements. This target also allows only the determination of the cut-off frequency.

Conversion Table:
Lines/Millimeter to Lines/Inch

Lines/mm	Lines/inch
0.25	6.35
0.50	12.7
1.00	25.4
2.00	50.8
4.00	101.6
8.00	203.1
16.00	406.4
32.00	812.8
64.00	1625.6
128.00	3251.2

Lines/Millimeter in USAF Resolving Power Test Target 1951

Element Number	Group Number			
	0	1	2	3
1	1.00	2.00	4.00	8.00
2	1.12	2.24	4.49	8.98
3	1.26	2.52	5.04	10.1
4	1.41	2.83	5.66	11.3
5	1.59	3.17	6.35	12.7
6	1.78	3.56	7.13	14.3

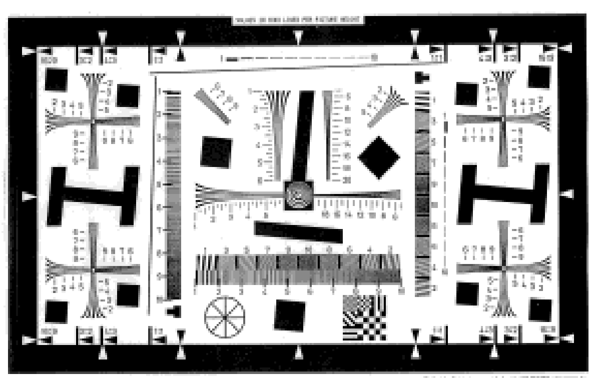


Fig. 30 Resolution test chart for electronic still photography. The black bars are used to calculate the modulation transfer function applying the moving knife-edge technique.

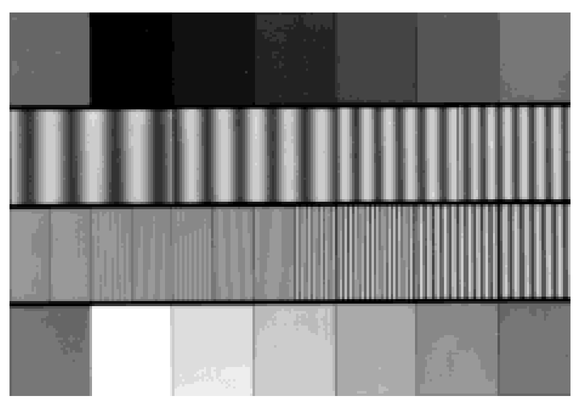


Fig. 31 Sine Patterns sine-wave target. The sine waves in the two center rows of the image are used to calculate the MTF. The MTF shows how much of the modulation that was in the original image made it into the pixel values of the scanned image of the target.

For future use (including color) Kodak's Q-60 test chart should be included.

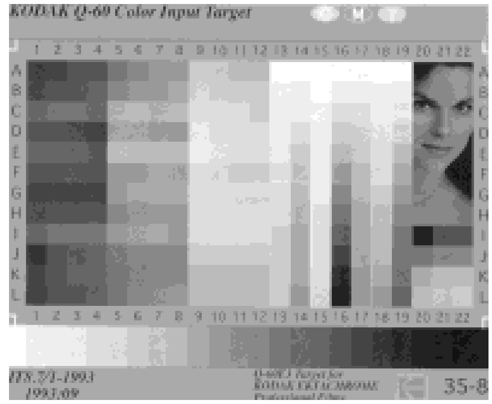


Fig. 32 Q-60 test target as reference for color images.

Digital Resolution—Do You Get What You Ask For?

How can you make sure that the digital files you get have been actually scanned at the desired resolution and not sampled up or down from another resolution?

A helpful method for finding out whether any resampling was done to your images is calculating the frequency spectrum of the image. Depending on the kind of resampling that was done, the frequency spectra will look different.

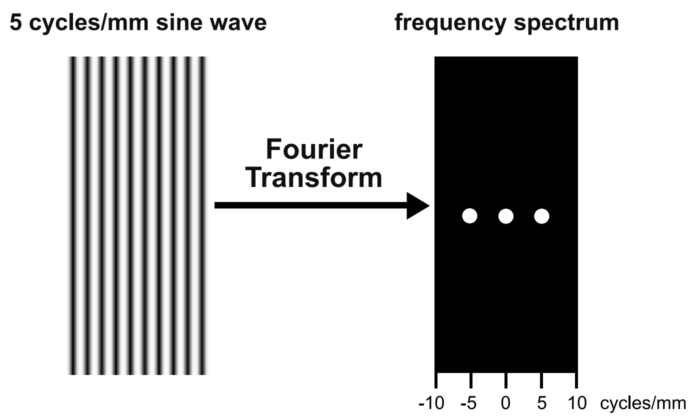


Fig. 33 Ideal frequency spectrum of a pure sine wave. Three spikes show up in the Fourier transform image.

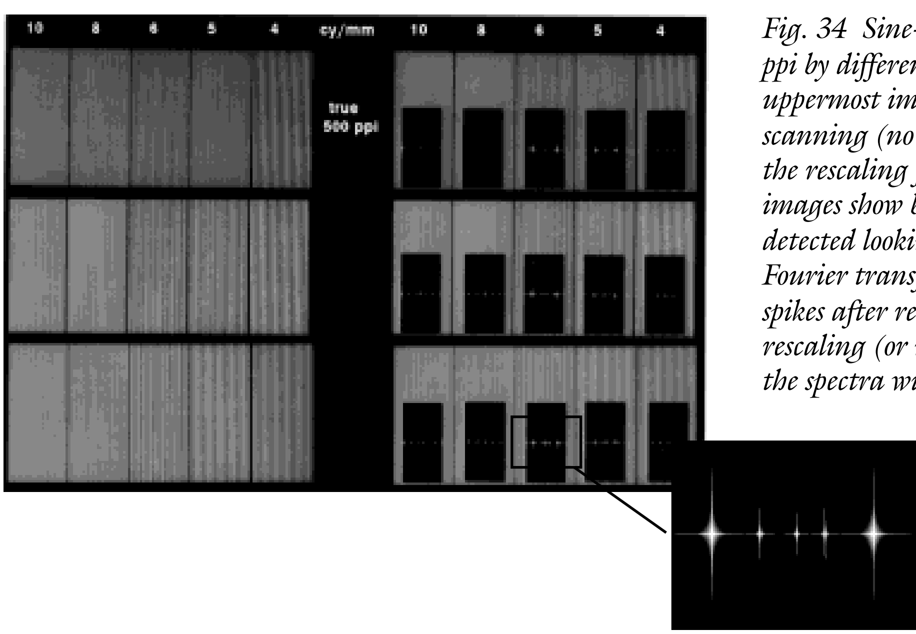


Fig. 34 Sine-wave targets rescaled to 500 ppi by different rescaling techniques. The uppermost image row shows true 500 ppi scanning (no rescaling). Depending on the rescaling function, the sine-wave images show banding. This can be easily detected looking at the enlargement of the Fourier transform image that shows five spikes after rescaling. Depending on the rescaling (or resampling) technique used, the spectra will look different.

Compression

For many years, storage space has been one of the major concerns when dealing with digital images. Advances in image-data compression and storage-media development have helped to reduce this concern. Nevertheless, image compression in an archival environment has to be evaluated very carefully. The image deterioration caused by the compression scheme limits the future use of a digital image. Because that use is not yet clear, one copy of every image should be compressed using a lossless compression scheme—even if it means paying the price of a lower compression ratio. Advances in image processing and pattern recognition will lead to better compression schemes in the future.

Lossless and Visually Lossless Compression

All good compression schemes sacrifice the least information possible in achieving a reduced file size. Lossless compression makes it possible to exactly reproduce the original image file from a compressed file. Lossless compression differs from visually lossless compression, which is compression where the artifacts are not visible. Although the human visual system provides guidelines for designing visually lossless compression schemes, ultimately the visibility of compression artifacts depends on the output.

LZW (Lossless Compression)

LZW (Lempel-Ziv-Welch) is a type of entropy-based encoding and belongs to a class of lossless compression that is performed on a digital image file to produce a smaller file which nevertheless contains all the information of the original file. For example, if an image contains a large red area, it may require less space to describe the size, shape, and color of that area than to individually specify the color of each pixel in that area. Entropy-based schemes are particularly effective on images which contain large blocks of smooth tones. Currently, the most common schemes are those based on Huffman encoding and the proprietary LZW compression (used for TIFF files in Adobe Photoshop).

The granular structure of film, unfortunately, hinders effective entropy-based encoding. The film grain imposes a fine random noise pattern on the image that does not compress well. There is currently no effective lossless way to deal with this problem.

Photo CD (Visually Lossless)

The Photo CD compression scheme utilizes both frequency and color compression in an attempt to produce visually lossless compression. A fundamental difference between Photo CD compression and JPEG compression is the fact that in the former the image is not broken up into blocks. Since the blocks can be a major source of visible artifacts with JPEG compression, this difference results in the Photo CD scheme having a decided advantage in terms of image quality. The disadvantage is a significant increase in computational requirements. It may take several minutes to uncompress a full-resolution Photo CD image on a "small" computer. The Photo CD system can implement whole-image transformation partly because there is an upper limit on the file size. Also, the image information in a Photo CD file is arranged in a pyramidal structure, with video and lower-resolution files being stored in uncompressed form. If a computer with limited computational capability is used to open a file, it is possible to access subsets of the data which are ordered according to spatial frequency. This structure allows a file to be opened at a lower resolution in a much shorter time because computations are performed only as required to produce the desired image resolution.

It has recently become possible to use Photo CD files the World Wide Web, and they can be easily incorporated into HTML files.

Lossy Compression

JPEG stands for Joint Photographic Expert Group, which is the group responsible for the development of the compression approach named after it. JPEG is one type of lossy compression with a number of user-selectable options. It divides the image into a number of 8 x 8-pixel blocks and then performs a Discrete Cosine Transform (DCT) on these blocks to transform the data into frequency space. The frequency space data is then requantized to a selectable number of bits, resulting in a significant reduction in the bit depth at high spatial frequencies.

The advantages of JPEG compression are its user selectability to ensure visually lossless compression, high compression ratio, good computational efficiency, and good film grain suppression characteristics. Future development proposed for the JPEG standard allow for tiling extensions, meaning that multiple-resolution versions of an image can be stored within the same file (similar to the concept behind the Photo CD files).

Fig. 35 JPEG lightly compressed (4:1/5:1) can already show some compression artifacts. Therefore the highest quality master file should be archived using a lossless compression algorithm.

The concern that repeated JPEG compression causes deterioration of image quality is valid. Consequently, all image processing should occur before the file is compressed, and the image should only be saved once using JPEG. Because the Library does not yet know the future use of the images (e.g., for reproduction) and the type of image processing that will be involved, one high-quality image file (a master) should be retained in a lossless compression scheme.

Monitor Calibration

A common problem when using different computer systems/monitors in an environment is the difference between the images when viewed on the various systems/monitors. In recent scanning projects this was a problem for the Library staff not only when working with images but also when discussing the quality of scans with vendors over the telephone, because the two parties did not see the same image. Therefore, it is a requirement to calibrate all the monitors. Nevertheless, one should be careful to base discussions entirely on images on the monitor.

The keys to calibrating a monitor are to set the gamma and white point. A monitor's gamma is a measure of the response curve of each of the red, green, and blue channels, from black to full intensity. Typical gamma values for color monitors are in the range from 1.8 to 2.2. The white point of a monitor is the color of white produced when all three color channels are at full intensity. It is specified as a color temperature, measured in Kelvin (with images getting bluer as their color temperatures rise). There exist various calibration tools that differ widely in complexity. Some application programs incorporate basic monitor calibration. Furthermore, there exist specific calibration programs. Depending on the need of the user they can be very sophisticated and incorporate devices like photometers and colorimeters.

The best way to view a monitor is under dim illumination that has a lower correlated color temperature than the monitor. This reduces veiling glare, increases the monitor dynamic range, and results in the human visual system adapting to the monitor. This viewing condition results in the most aesthetically pleasing monitor images. The situation gets more problematic if originals and images on the screen are viewed side-by-side, because in this case the observers are not allowed to adapt to each "environment" individually.

Once calibrated, the monitor should need recalibration only when conditions change, or on a monthly basis. It is a good idea to put a piece of tape over the monitor's brightness and contrast controls after calibration and to maintain consistent lighting conditions.

Suggested Hardware (Including Monitor Calibration Tool)

To judge images on a monitor, a good monitor/video card combination should be available. The PC should have enough RAM to be able to work efficiently with the highest-resolution images. IPI worked with the following equipment:

Nanao FX2-21 Monitor

#9 Imagine Pro 8MB Graphic Card

For a calibration tool, IPI recommends Colorific from Sonnetech, Ltd. (included with the monitor suggested above).

Intel Pentium 200Mhz motherboard

64MB of RAM

Adaptec wide SCSI controller

Seagate 4.2GB wide SCSI hard drive

Plextor 6x CD ROM drive

HP ScanJet 3c flatbed scanner with an optical resolution of 600 dpi

Kontron Digital Camera ProgRes 3012, highest spatial resolution 3000 x 2300 pixels (scans provided by JJT Consulting, Inc., Thorndale, TX)

For documents, image quality should also be tested on printed output from different printers

The following software packages have been used for the interpretation and creation of the images:

Adobe Photoshop 3.0

Impact Professional

IDL 4.0

Closing Note

The quality review of scanned images incorporates much more than a specification issue, e.g., how many ppi are required for scanning the documents. Most of the major scanning projects that scan for archiving are now going through this phase of setting up a complete framework. By further investigation of such a framework, the Library can take a leadership position in the field.

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AIIM, Association for Information and Image Management
1100 Wayne Avenue, Suite 1100
Silver Spring, MD 20910
Fax 301-587-2711

Quality Index Test Image/High Contrast Resolution Test Image
Picture Elements, Inc.
777 Panoramic Way
Berkeley, CA 94704

Resolution Test Chart for Electronic Still Photography
ISO/TC42
WG18/"Electronic Still Picture Imaging"

RIT Alphanumeric Test Target
Rochester Institute of Technology
Research and Testing
Technical and Education Center of the Graphic Arts
66 Lomb Memorial Drive
Rochester, NY 14623-5604
Fax 716-475-6510

Scanner Test Target PM-189
A&P International
2715 Upper Afton Road
St. Paul, MN 55119-4760
Phone 612-738-9329
Fax 612-738-1496

Sine Wave Pattern
Sine Patterns
236 Henderson Drive
Penfield, NY 14526
Phone 716-248-5338
Fax 716-248-8323

Illustrations by Karen Santoro, IPI